(12) UK Patent Application (19) GB (11) 2 355 766 (13) A

(43) Date of A Publication 02.05.2001

(21) Application No 0025727.9

(22) Date of Filing 20.10.2000

(30) Priority Data
(31) 9925193 (32) 26.10.1999 (33) GB

(71) Applicant(s)
Rolls-Royce plc
(Incorporated in the United Kingdom)
65 Buckingham Gate, LONDON, SW1E 6AT, United Kingdom

(72) Inventor(s)
Paul Jonathan Railton Strange
Craig John Mead

(74) Agent and/or Address for Service
M A Gunn
Rolls-Royce plc, Patents Department, PO Box 31, Moor Lane, DERBY, DE24 8BJ, United Kingdom

(51) INT CL^7
F02K 1/46

(52) UK CL (Edition S)
F1J JCH JCN

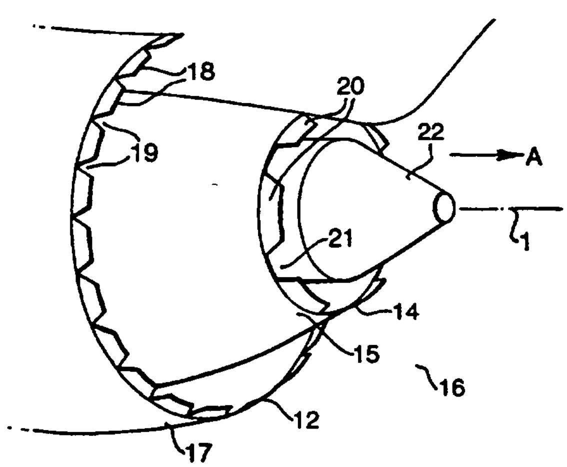
(56) Documents Cited
GB 2289921 A GB 1603944 A GB 0766985 A
EP 0999358 A2 EP 0984152 A2 US 4284170 A

(58) Field of Search
UK CL (Edition S) F1J JCE JCH JCK JCN
INT CL^7 F02K 1/00 1/46
ONLINE:EPODOC,JAPIO,WPI

(54) Abstract Title
Gas turbine engine exhaust nozzle having noise reduction tabs

(57) A gas turbine engine exhaust nozzle 16 for reducing exhaust noise comprises a substantially frusto-conical nozzle wall 15,17, and a plurality of circumferentially disposed nozzle tabs 18,20 which extend in a generally downstream direction from a downstream periphery of the nozzle wall 15,17. The nozzle tabs 18,20 are radially inwardly angled at an angle (β, fig 3) of up to 20°, but preferably up to 10°, relative to the nozzle wall 15,17. Preferably tabs 18,20 are trapezoidally shaped with trapezoidally shaped notches 21 or V shaped notches 19 between adjacent tabs 18,20. The angled tabs 18,20 are particularly suitable for a ducted fan gas turbine engine and can be provided on one or both of the core exhaust nozzle 14 or the bypass exhaust nozzle 12. Alternatively, a bypass exhaust nozzle 12 with angled tabs 18 can also be used with a core exhaust nozzle of the lobed mixer type. Broadband shock associated noise is improved by a frequency shift to more readily attenuated higher frequency noise and a reduction in noise at lower frequencies (fig 4).

Fig.2.



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

GB 2 355 766 A

Fig.1.

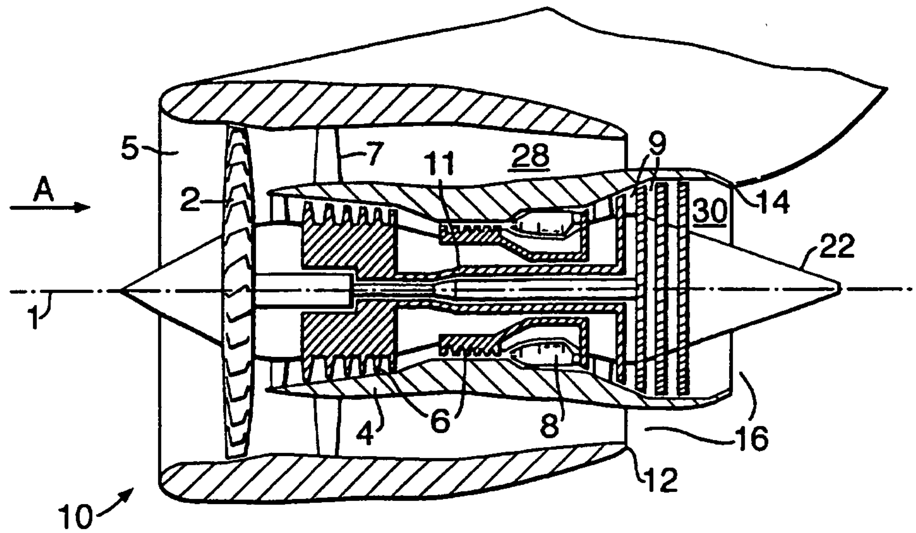


Fig.2.

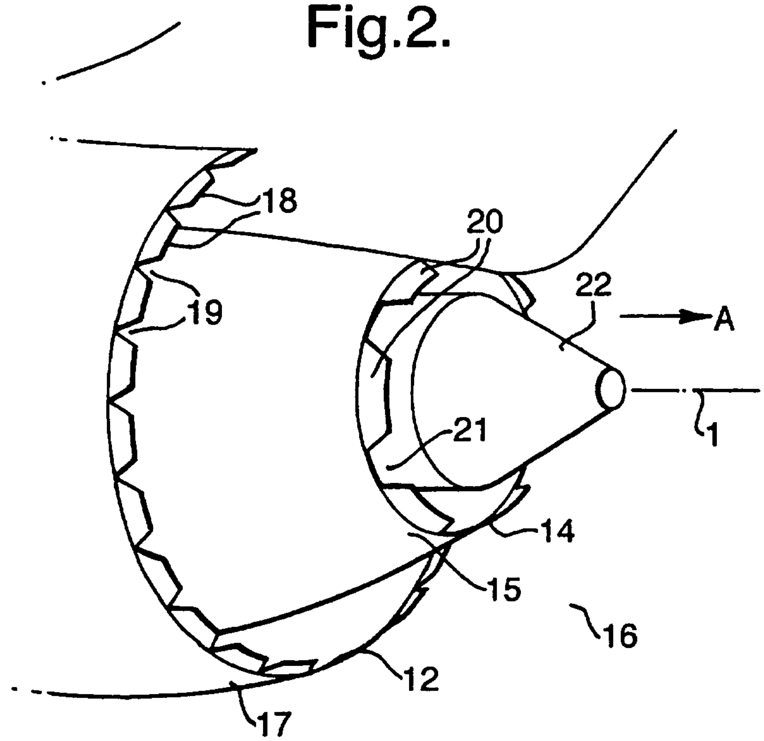


Fig.3.

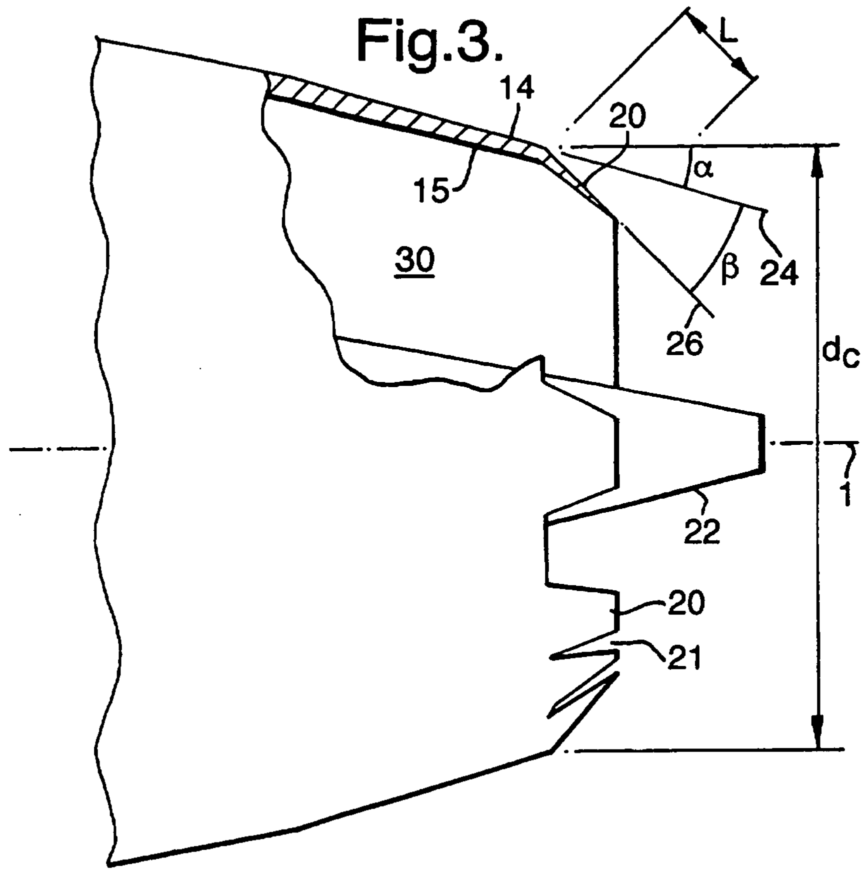
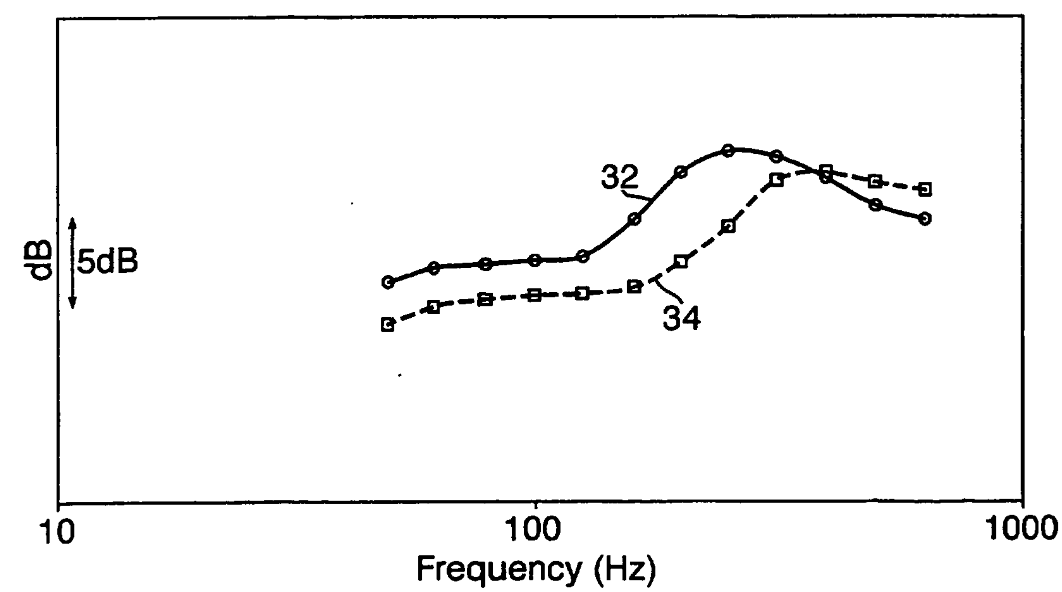

L
14
20
α
15
30
β
24
26
dC
1
22
20
21

Fig.4.


32
34
dB
5dB
10
100
1000
Frequency (Hz)

Gas Turbine Engine Exhaust Nozzle

The present invention relates generally to gas turbine engine exhaust nozzles, and in particular to noise reduction improvements to nozzle arrangements used on gas turbine engines used for aircraft propulsion.

Gas turbine engines are widely used to power aircraft. As is well known, the engine basically provides propulsive power by generating a high velocity stream of gas which is exhausted rearwards through an exhaust nozzle. A single high velocity gas stream is produced by a turbojet gas turbine engine. More commonly nowadays however two streams, a core exhaust and a bypass exhaust, are generated by a ducted fan gas turbine engine or bypass gas turbine engine.

The high velocity gas stream produced by gas turbine engines generates a significant amount of noise, which is referred to as exhaust noise. This noise is generated due to the high velocity of the exhaust stream, or streams, and the mixing of the streams with the surrounding atmosphere, and in the case of two streams, as the bypass and core streams mix. The degree of the noise generated is determined by the velocity of the stream and how the streams mix as they exhaust through the exhaust nozzle.

Increasing environmental concerns require that the noise produced by gas turbine engines, and in particular aircraft gas turbine engines, is reduced and there has been considerable work carried out to reduce the noise produced by the mixing of the high velocity gas stream(s). A large number of various exhaust nozzle designs have been used and proposed to control and modify how the high velocity exhaust gas streams mix. With ducted fan gas turbine engines particular attention has been paid to the core stream and the mixing of the core and bypass exhaust streams. This is because the core stream velocity is considerably greater than the bypass stream and also the surrounding atmosphere and consequently the core exhaust stream generates a significant amount of the

exhaust noise. Mixing of the core stream with the bypass stream has also been found to generate a significant proportion of the exhaust noise due to the difference in velocity of the core and bypass streams.

One common current exhaust nozzle design that is widely used is a lobed type nozzle which comprises a convoluted lobed core nozzle (sometimes called a mixer) with alternate circumferentially disposed lobes which direct the core exhaust stream radially outwardly into bypass exhaust stream, and the bypass exhaust stream radially inwardly into the core exhaust stream as well as generating mixing flows between the two streams. This forces the streams to mix which improves the mixing of the streams and so reduces the noise generated. Whilst providing a degree of noise suppression this type of nozzle is relatively complex both to manufacture and design. Furthermore when such nozzles are applied to high bypass ratio turbofan engines the performance and aerodynamic losses generated by the lobed mixer are significant. In addition such nozzles generally require, for optimum performance, an extended bypass nozzle with the downstream end of the bypass nozzle disposed downstream of the downstream end of the lobed core nozzle/mixer. This adds considerable weight, drag, and cost to the installation and nowadays short bypass nozzles are favoured with which the lobed type core nozzles are less effective and are also more detrimental to the engine performance than when used on a long cowl arrangement.

An alternative nozzle design that is directed to reducing exhaust noise is proposed and described in GB 2,289,921. In this proposal a number of circumferentially spaced notches, of various specified configurations, sizes, spacing and shapes, are provided in the downstream periphery of a generally circular core exhaust nozzle. Such a nozzle design is considerably simpler to manufacture than the conventional lobed designs. This prior proposal describes that the notches generate vortices in the exhaust streams.

These vortices enhance and control the mixing of the core and bypass streams which it is claimed reduces the exhaust noise.

Model testing of nozzles similar to those described in GB 2,289,921 has shown that significant noise reduction and suppression can be achieved. However the parameters and details of the design proposed in GB 2,289,921 are not optimal and there is a continual desire to improve the nozzle design further.

It is therefore desirable to provide an improved gas turbine engine exhaust nozzle which is quieter than conventional exhaust nozzles and/or which offers improvements generally.

According to a first aspect of the present invention there is provided a gas turbine engine exhaust nozzle comprising a substantially frusto-conical nozzle wall, and a plurality of circumferentially disposed nozzle tabs which extend in a generally downstream direction from a downstream periphery of the nozzle wall; characterised in that the nozzle tabs are radially inwardly angled at an angle of up to 20° relative to the nozzle wall.

An exhaust nozzle as described above provides improved exhaust noise characteristics. It is believed that the angling of the tabs, at angles up to 20°, generates stronger vortices in an exhaust flow through the nozzle. These stronger vortices provide improved control and enhanced mixing of the exhaust flow so reducing the perceived exhaust noise generated by the exhaust flow.

Preferably the tabs circumferentially taper in a downstream direction. The tabs may particularly be of a substantially trapezoidal shape. Alternatively the tabs may be of a substantially rectangular or square shape.

Preferably the tabs are circumferentially disposed about the periphery of the nozzle to define substantially trapezoidally shaped notches between adjacent tabs. Alternatively the tabs may be circumferentially disposed

about the periphery of the nozzle to define substantially V shaped notches between adjacent tabs.

The edges of the tabs may be curved.

Preferably the nozzle tabs are radially inwardly angled at an angle of up to 10° relative to the nozzle wall.

Preferably the exhaust nozzle is a core engine nozzle. The exhaust nozzle may also or alternatively be a bypass exhaust nozzle.

According to a second aspect of the present invention there is provided a ducted fan gas turbine engine exhaust nozzle assembly comprising a core exhaust nozzle and a bypass exhaust nozzle both as described above and/or as claimed in any one of claims 1 to 8.

The ducted fan gas turbine engine exhaust nozzle assembly may comprise an outer bypass exhaust nozzle as described above and/or as claimed in any one of claims 1 to 8, and an inner core exhaust nozzle of a lobed mixer type.

Preferably the downstream end of the bypass nozzle is upstream of the downstream periphery of the core exhaust nozzle. Alternatively the downstream end of the bypass nozzle is further downstream than the downstream periphery of the core exhaust nozzle.

The present invention will now be described by way of example only with reference to the following figures in which:

Figure 1 is a schematic section of a ducted fan gas turbine engine incorporating a exhaust nozzle according to the present invention;

Figure 2 is a more detailed schematic perspective view of the exhaust nozzle of the ducted fan gas turbine engine shown in figure 1;

Figure 3 a part cutaway schematic view of the core exhaust nozzle of the ducted fan gas turbine engine and exhaust nozzle shown in figures 1 and 2.

Figure 4 shows the effect of nozzle tabs on broadband shock-associated noise against frequency for model data scaled to full size, in a loss-less atmosphere.

With reference to figure 1 a ducted fan gas turbine engine 10 comprises, in axial flow series an air intake 5, a propulsive fan 2, a core engine 4 and an exhaust nozzle assembly 16 all disposed about a central engine axis 1. The core engine 4 comprises, in axial flow series, a series of compressors 6, a combustor 8, and a series of turbines 9. The direction of airflow through the engine 10 in operation is shown by arrow A and the terms upstream and downstream used throughout this description are used with reference to this general flow direction. Air is drawn in through the air intake 5 and is compressed and accelerated by the fan 2. The air from the fan 2 is split between a core engine 4 flow and a bypass flow. The core engine 4 flow enters core engine 4, flows through the core engine compressors 6 where it is further compressed, and into the combustor 8 where it is mixed with fuel which is supplied to, and burnt within the combustor 8. Combustion of the fuel with the compressed air from the compressors 6 generates a high energy and velocity gas stream which exits the combustor 8 and flows downstream through the turbines 9. As the high energy gas stream flows through the turbines 9 it rotates turbine rotors extracting energy from the gas stream which is used to drive the fan 2 and compressors 6 via engine shafts 11 which drivingly connect the turbine 9 rotors with the compressors 6 and fan 2. Having flowed through the turbines 9 the high energy gas stream from the combustor 8 still has a significant amount of energy and velocity and it is exhausted, as a core exhaust stream, through the engine exhaust nozzle assembly 16 to provide propulsive thrust. The remainder of the air from, and accelerated by, the fan 2 flows within a bypass duct 7 around the core engine 4. This bypass air flow, which has been accelerated by the fan 2, flows to the exhaust nozzle assembly 16 where it is exhausted, as a bypass exhaust stream

to provide further, and in fact the majority of, the useful propulsive thrust.

The velocity of the bypass exhaust stream is significantly lower than that of the core exhaust stream. Turbulent mixing of the two exhaust streams in the region of, and downstream of, the exhaust nozzle assembly 16, as well as mixing of both streams with the ambient air surrounding and downstream of the exhaust 16 generates a large component of the noise generated by the engine 10. This noise is known as exhaust noise. Effective mixing and control of the mixing of the two exhaust streams with each other and the ambient air is required in order to reduce noise generated. The mixing and its control is effected by the exhaust nozzle assembly 16.

In the embodiment shown the exhaust nozzle assembly 16 comprises two concentric sections, namely a radially outer bypass exhaust nozzle 12 and an inner core exhaust nozzle 14. The core exhaust nozzle 14 is defined by a generally frusto-conical core nozzle wall 15. This defines the outer extent of an annular core exhaust duct 30 through which the core engine flow is exhausted from the core engine 4. The inner extent of the core exhaust duct 30 is defined by an engine plug structure 22. A plurality of circumferentially spaced tabs 20 extend from the downstream end of the core exhaust nozzle 14 and core nozzle walls 15. The tabs 20 and exhaust nozzles 12,14 are shown more clearly in figure 2. As shown the tabs 20 are of a trapezoidal shape with the sides of the tabs 20 circumferentially tapering towards each other in the downstream direction. The tabs 20 are evenly circumferentially disposed so that a notch 21 or space is defined by and between adjacent tabs 20. The notches 21 are complimentary to the shape of the tab 20 and accordingly are of a trapezoidal shape on the core nozzle 14, with the notches 21 circumferentially opening out in a downstream direction.

The nozzle 14 is generally similar to those described and shown in GB 2,289,921 which is incorporated herein by reference. The number of tabs 20, and so notches 21 defined in the core exhaust nozzle 14 and also bypass exhaust nozzle 12 (described below), the width of the notches 21, angle of the notches 21, width of notch 21, angular offset between notches 21, and angular gap between notches 21 are all essentially the same and within the same ranges as described in GB 2,289,921. It should be noted however that in GB 2,289,921 only the core nozzle 14 is provided with tabs 20 and notches 21 whereas, as described below, according to the present invention the bypass exhaust nozzle 12 may also be provided with tabs 20 and notches 21.

Referring to figure 3, the tabs 20 of the core exhaust nozzle 14 are radially inwardly angled so that the tabs 20 impinge into the core duct 30 (relative to an extended line 24, shown in figure 3, of the profile of the core nozzle wall 15 immediately upstream of the tabs 20) and are, in operation, incident on the core exhaust flow which is exhausted through the core exhaust nozzle 14. The angle of incidence β of the tabs 20 is defined relative to an extended line 24 of the profile of the core exhaust nozzle wall 15 immediately upstream of the tabs 20. The profile of the core nozzle wall 15 immediately upstream of the tabs 20 itself is at an angle α (typically between 10° and 20°) to the engine axis 1.

It has been found that by angling the tabs 20, and the angle of incidence β, has a effect on noise suppression. As the angle of incidence β is increased up to 20° the noise reductions are improved. However at angles of incidence β above 20° there is little further improvement in noise suppression. Furthermore at these higher angles of incidence β aerodynamic losses due to the effect the tabs 20 have on the core exhaust flow increase. Therefore preferably the tabs 20 are angled at angles of incidence β up to 10°.

The tabs 20 and angling of the tabs 20 reduces the mid and low frequency noise generated by the exhaust and engine 10, typically in the frequency range 50-500 kHz. It does however, in some cases increase the noise generated at higher frequencies. The noise at low and mid frequencies though is the most critical in terms of the perceived noise level and the higher frequency noise is masked by noise generated from elsewhere in the engine 10. Therefore overall the tabs 20 provide a reduction in the perceived exhaust noise generated. The increase in high frequency noise sometimes associated with the angled tabs 20 at higher angles of incidence β is a further reason why the tabs 20 are preferably angled at angles of incidence β up to 10°.

It is believed that the tabs 20 induce streamwise vortices in the exhaust flow through and around the nozzle 14. These vortices are generated and shed from the sides of the tabs 20 and increase the local turbulence levels in a shear layer that develops between the core and bypass exhaust streams downstream of the exhaust nozzle assembly 16. This vorticity and turbulence increases and controls the rate of mixing between the core exhaust stream, bypass exhaust stream, and the ambient air. This reduces the velocities downstream of the exhaust assembly 16, as compared to a conventional nozzle, and so reduces the mid to low frequency noise generated by the exhaust streams. The increased turbulence generated by the tabs 20 in the initial part of the shear layers immediately downstream of the exhaust nozzle assembly 16 causes an increase in the high frequency noise generated. Angling of the tabs 20 radially inwards increases the strength of the vortices produced and so improves the reduction in perceived noise. However the angle of incidence β of the tabs 20 must not be too large since this can induce flow separation which will generate, rather than reduce the noise as well as adversely affecting aerodynamic performance of the nozzle 14.

The bypass exhaust nozzle 12 is also defined by a generally frusto-conical bypass nozzle wall 17 which is concentric with and disposed radially outwardly of the core exhaust nozzle 14. The bypass nozzle wall 17 defines the outer extent of an annular bypass exhaust duct 28 through which the bypass engine flow is exhausted from the engine 10. The inner extent of the bypass exhaust duct 28 is defined by an outer wall of the core engine 4. The bypass nozzle is similar to the core exhaust nozzle 14 and a plurality of circumferentially spaced tabs 18 extend from the downstream end of the bypass exhaust nozzle 12 and bypass nozzle walls 17. As with the core nozzle 14, the tabs 18 are of a trapezoidal shape with the sides of the tabs 18 circumferentially tapering in the downstream direction. The tabs 18 are evenly circumferentially disposed so that a V shaped notch 19 or space is defined by and between adjacent tabs 18. The bypass nozzle tabs 18 affect the bypass exhaust flow and noise generated in a similar way to the core exhaust nozzle tabs 20.

Increasing the number of vortices generated with such exhaust nozzle designs, by providing more tabs 18,20 around the circumference of the nozzle 12,14 further reduces the exhaust noise generated. However experiments have indicated that a minimum spacing of the vortices, and so spacing and circumferential width of the tabs 18,20, must be maintained in order to reduce interaction and coalescence of the vortices. Coalescence and interaction of the vortices reduces the noise suppression provided by such exhaust nozzle 12,14 designs. In particular it has been found that the separation between vortices produced from the same tab 18,20 (and so circumferential width of the tab 18,20) must be greater than the separation (and so circumferential width of notch 19,21) between vortices produced from adjacent tabs 18,20. This is due to the direction of rotation of the vortices produced, with the vortices generated from the same tab 18,20 rotating

in such a way that they are more likely to interact and coalesce.

It is due to this reason that trapezoidal tabs 18,20 are preferred. It will be appreciated though that square or rectangular tabs could also be used. The edges of the tabs 18,20 and the tabs 18,20 themselves could also be curved. Triangular tabs are not however desirable since the vortices produced from either side of such a tab will tend to be coincident therefore producing less vortices of reduced strength around the circumference and so less noise reduction. The length of such a tab is also longer than required so adding unnecessary weight to the exhaust nozzle 12,14, and adding further aerodynamic drag and a performance loss without significantly improving the noise. Furthermore the stress produce in such a shaped tab will tend to increase the likelihood of mechanical failure of such a triangular tab in operation.

With the arrangement of tabs 18 shown on the bypass exhaust nozzle 12, with V notches 19 between tabs 18, a large number of tabs 18 and so a larger number of vortices can be generated whilst still maintaining the required separation of the vortices. A similar arrangement could be used on the core exhaust nozzle 14, however due to the smaller diameter of the core exhaust nozzle 14 a trapezoidal shaped notch 21 is preferred to provide the required separation between adjacent tabs 20. Furthermore on smaller diameter nozzles, such as the core exhaust nozzle 14, it has been found that use of V shaped notches may restrict flow between the tabs which reduces the strength and generation of the individual vortices produced and so the noise suppression. This may outweigh the advantages of generating more vortices by providing more tabs. In addition V shaped notches result in a stress concentration at their apex which in high stress situations can lead to stress problems and failure of the nozzle.

The aerodynamic performance affect of V shaped notches is however better than trapezoidal notches with V shaped notches being aerodynamically more efficient. Since the bypass exhaust provides the majority of the engine thrust loss of aerodynamic performance of the bypass exhaust nozzle 12 has a greater affect on overall engine performance than the aerodynamic performance of the core exhaust nozzle 14. Consequently it is preferable to use V shaped notches on the bypass exhaust nozzle 12 and accept any problems described above that they may cause. On the core exhaust nozzle 14 however since the aerodynamic performance losses are less significant trapezoidal shaped notches are preferred to eliminate the above problems.

It is believed that the angling of the tabs 18,20 is most beneficial on the core exhaust nozzle 14. This is because the relative pressure difference between the core and bypass is greater than that between the bypass and the ambient surrounding air with the result that the bypass exhaust stream restricts and constrains the core exhaust stream more than the ambient atmosphere restricts and constrains the bypass exhaust stream. Consequently, in order to enhance and control the mixing of the core exhaust stream and provide noise suppression, stronger vortices, generated by angled tabs 18,20, are required to be generated at the core exhaust to overcome the effect of the bypass exhaust stream radially outside of the core exhaust stream.

The tabs 20 should have a length L sufficient to generate the required streamwise vortices as described below and GB 2,289,921 specifies that the tabs 18,20 must have a length L of between 5% to 50% of the nozzle diameter Dc, Db. It has been found however that using long tabs, towards the 50% end of the range given, induces excessive aerodynamic losses which adversely affect the performance particularly when they are angled. Accordingly it has been determined that the core tabs 20 should have a length L of approximately 10% of the core exhaust nozzle diameter Dc, whilst the bypass

tabs 18 should have a length L of approximately 5% of the bypass exhaust nozzle diameter Db. The bypass tabs 18 have a smaller percentage length since the bypass provides more of the propulsive thrust of the engine and so any performance loss on the bypass will have a greater affect on the overall engine performance. In addition although the percentage size is less, since the bypass is of a greater diameter than the core the actual physical size of the core tabs 20 and bypass tabs 20 not so different.

In model tests of the exhaust nozzle assembly 16 shown in figure 2 and described above a 5dB reduction in the peak sound pressure level over a conventional plain frusto conical nozzle arrangement has been achieved. It has also been found that the noise reductions provided by using tabs 18 on the bypass exhaust nozzle 12 and by using tabs 20 on the core exhaust nozzle 14 are cumulative. It will therefore be appreciated that in other embodiments tabs 18,20 can be used on the bypass exhaust nozzle 12 or the core exhaust nozzle 14 alone to give some improved degree of noise suppression. The core exhaust nozzle tabs 20 and the bypass exhaust nozzle tabs 18 can also be angled at different angles of incidence β.

Figure 4 shows the effect of nozzle tabs 18, 20 on broadband shock-associated noise for model data scaled to full size, in a loss-less atmosphere. Figure 4 is associated to test results derived from an arrangement of tabs 18, 20 as shown in figure 2.

When the pressure ratio of a convergent nozzle assembly 16 becomes supercritical the exhaust flow downstream of the nozzle 12, 14 becomes over expanded and shocks are formed in the exhaust flow. The presence of the shocks results in an additional noise source known as broadband shock-associated noise. This shock-associated noise source occurs in jets from both single and coaxial nozzles and can be heard in the cabin of passenger aircraft (not shown) at cruise conditions. Such high noise levels also occur at the top of the climb

segment of an aircraft flight path, but are more annoying to passengers at cruise due to the amount of time spent under cruise conditions.

As the noise propagates from the engine 10 to the cabin there will be a small amount of attenuation by the atmosphere. However, in order to reduce the noise in the cabin to comfortable or acceptable levels the airframe manufacturers need to take measures to attenuate the noise as it propagates through the aircraft fuselage. Since the noise can reach the cabin via a number of transmission paths, such treatment inevitably results in significant increases in the cost and weight of the aircraft.

Application of the nozzle tabs 18, 20 as described herein, and in particular those applied to the bypass nozzle 12, results in an increase in the frequency of the peak shock noise. These higher frequencies are more readily attenuated by acoustic treatment and the increase in frequency therefore assists in reducing the noise levels in the cabin. Furthermore, it could reduce the cost and weight of the fuselage acoustic treatment for the same cabin noise level since it does not need to be so extreme.

Figure 4 shows experimental results obtained during a model-scale rig test of a high bypass ratio engine exhaust 16 at typical cruise nozzle pressure ratios. Figure 4 shows the effect of nozzle tabs 18, 20 on broadband shock-associated noise against frequency for model data scaled to full size, in a loss-less atmosphere. Line 32 relates to an exhaust with no tabs and line 34 relates to the exhaust 16 having tabs 18, 20 as displayed in figure 2. It can be seen that there is a frequency shift and a general reduction in noise up to a certain frequency. The shift of peak noise from one frequency to a higher frequency is beneficial as the higher frequency noise is attenuated more readily and is less obtrusive to passengers in the cabin.

Furthermore in yet further embodiments of the invention a bypass exhaust nozzle using tabs as described above can be

used in conjunction with a conventional forced lobed type core exhaust nozzle/mixer. Such an arrangement has also been tested and has shown improved noise suppression over an exhaust assembly which uses a lobed type core nozzle/mixer with a conventional bypass exhaust nozzle.

Although the invention has been described and shown with reference to a short cowl type engine arrangement in which the bypass duct 28 and bypass exhaust nozzle 12 terminate upstream of the core exhaust duct 30 and nozzle 14, the invention may also be applied, in other embodiments, to long cowl type engine arrangements in which the bypass duct 28 and bypass exhaust nozzle 12 terminate downstream of the core exhaust duct 20 and nozzle 14. The invention however is particularly beneficial to short cowl arrangements since with such arrangements conventional noise suppression treatments of the exhaust are not practical in particular where high by pass ratios are also used.

The invention is also not limited to ducted fan gas turbine engines 10 with which in this embodiment it has been described and to which the invention is particularly suited. In other embodiments it can be applied to other gas turbine engine arrangements in which either two exhaust streams, one exhaust stream or any number of exhaust streams are exhausted from the engine though an exhaust nozzle(s).

Claims

1. A gas turbine engine exhaust nozzle comprising a substantially frusto-conical nozzle wall, and a plurality of circumferentially disposed nozzle tabs which extend in a generally downstream direction from a downstream periphery of the nozzle wall;

characterised in that the nozzle tabs are radially inwardly angled at an angle of up to 20° relative to the nozzle wall.

2. A gas turbine engine exhaust nozzle as claimed in claim 1 in which the tabs circumferentially taper in a downstream direction.

3. A gas turbine engine exhaust nozzle as claimed in claim 1 or 2 in which the tabs are of a substantially trapezoidal shape.

4. A gas turbine engine exhaust nozzle as claimed in claim 1 in which the tabs are of a substantially rectangular or square shape.

5. A gas turbine engine exhaust nozzle as claimed in any one of claims 1 to 3 in which the tabs are circumferentially disposed about the periphery of the nozzle to define substantially trapezoidally shaped notches between adjacent tabs.

6. A gas turbine engine exhaust nozzle as claimed in any one of claims 1 to 3 in which the tabs circumferentially disposed about the periphery of the nozzle to define substantially V shaped notches between adjacent tabs.

7. A gas turbine engine exhaust nozzle as claimed in any one of the preceding claims in which the edges of the tabs are curved.

8. A gas turbine engine exhaust nozzle as claimed in any preceding claim in which the nozzle tabs are radially inwardly angled at an angle of up to 10° relative to the nozzle wall.

9. A gas turbine engine exhaust nozzle as claimed in any preceding claim in which the exhaust nozzle is a core engine nozzle.

10. A gas turbine engine exhaust nozzle as claimed in any preceding claim in which the exhaust nozzle is a bypass exhaust nozzle.

11. A ducted fan gas turbine engine exhaust nozzle assembly comprising a core exhaust nozzle and a bypass exhaust nozzle both as claimed in any preceding.

12. A ducted fan gas turbine engine exhaust nozzle assembly comprising an outer bypass exhaust nozzle as claimed in any one of claims 1 to 8, and an inner core exhaust nozzle of a lobed mixer type.

13. A ducted fan gas turbine engine exhaust nozzle assembly as claimed in claim 12 in which the downstream end of the bypass nozzle is further downstream than the downstream periphery of the core exhaust nozzle.

14. A ducted fan gas turbine engine exhaust nozzle assembly as claimed in claim 10 in which the downstream end of the bypass nozzle is upstream of the downstream periphery of the core exhaust nozzle.

15. A gas turbine engine exhaust nozzle as hereinbefore described with reference to figures 1 to 3.

16. A ducted fan gas turbine engine as hereinbefore described with reference to figures 1 to 3.

The Patent Office

PATENTS • DESIGNS • COPYRIGHT • TRADE MARKS

CHARTER MARK

INVESTOR IN PEOPLE

-17-

Application No:	GB 0025727.9	**Examiner:**	Terence Newhouse
Claims searched:	1-14	**Date of search:**	31 January 2001

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): F1J(JCE,JCH,JCK,JCN)

Int Cl (Ed.7): F02K 1/00 1/46

Other: ONLINE: EPODOC, JAPIO, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB 2289921 A	(HARRIS), see fig 2 noting tabs between notches 9	
X	GB 1603944 A	(SOCIETE), see fig 1 noting nozzle 1 and tabs 3	1,4,5,8
X	GB 0766985 A	(CRANFIELD), see fig 22 noting nozzle 48 and tabs 4	1,4,8
X,P	EP 0999358 A2	(UNITED TECHNOLOGIES), see col 4 lines 32-38	1 at least
X,P	EP 0984152 A2	(UNITED TECHNOLOGIES), see col 4 line 50 - col 5 line 3	1 at least
X	US 4284170	(UNITED TECHNOLOGIES), see fig 2 noting nozzle 12 and tabs 16	1,2,5,8,9

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.